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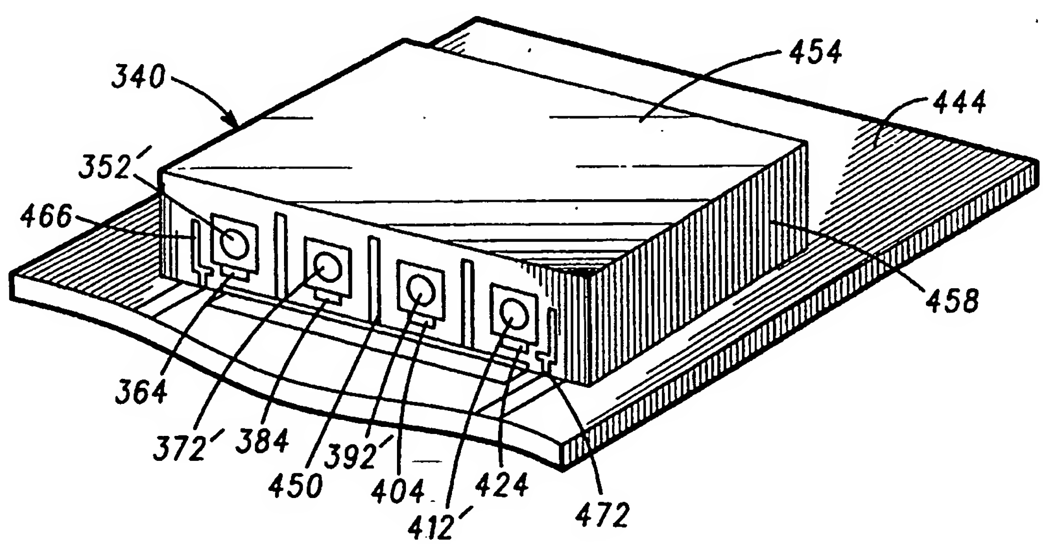


(57) Abstract

A tunable filter circuit (340) has a ceramic block forming a portion thereof. Transmission lines (352', 372', 392', 412') are formed of resonating cavities which extend through the ceramic block, and variable capacitors (364, 384, 404, 424) capacitively load the transmission lines (352', 372', 392', 412'). By varying the capacitance of the variable capacitors (364, 384, 404, 424), the filter characteristics of the filter circuit comprised of the ceramic block and the variable capacitors is varied. The tunable filter circuit (340) may, for example, comprise a portion of a cellular radiotelephone operative in a TDMA communication scheme.

TUNABLE FILTER CIRCUIT AND METHOD THEREFOR

Background of the Invention

The present invention relates generally to filter circuitry and, more particularly, to a tunable filter circuit for a transceiver operable alternately to transmit or to receive modulated signals.

A communication system is comprised, at a minimum, of a transmitter and a receiver interconnected by a communication channel. A communication signal is transmitted by the transmitter upon the transmission channel to be received by the receiver. A radio communication system is a communication system in which the transmission channel comprises a radio frequency channel defined by a range of frequencies of the electromagnetic frequency spectrum. A transmitter operative in a radio communication system must convert the communication signal into a form suitable for transmission upon the radio-frequency channel.

Conversion of the communication signal into a form suitable for transmission upon the radio-frequency channel is effectuated by a process referred to as modulation. In such a process, the communication signal is impressed upon an electromagnetic wave. The electromagnetic wave is commonly referred to as a "carrier signal." The resultant signal, once modulated by the communication signal, is commonly referred to as a modulated carrier signal or, more simply, a modulated signal. The transmitter includes circuitry operative to perform such a modulation process.

Because the modulated carrier signal may be transmitted through free space over large distances, radio communication systems are widely utilized to effectuate communication between a transmitter and a remotely-positioned receiver.

The receiver of the radio communication system which receives the modulated carrier signal contains circuitry analogous to, but operative in a manner reverse with that of, the circuitry of the

transmitter and is operative to perform a process referred to as demodulation.

Numerous modulated carrier signals may be simultaneously transmitted upon differing radio frequency channels of the electromagnetic frequency spectrum. Regulatory bodies have divided portions of the electromagnetic frequency spectrum into frequency bands, and have regulated transmission of the modulated carrier signals upon various ones of the frequency bands. (Frequency bands are further divided into channels, and such channels form the radio-frequency channels of a radio communication system. Such channels shall, at times, be referred to hereinbelow by the term conventionally-defined frequency channels.)

A two-way radio communication system is a radio communication system, similar to the radio communication system above-described, but which permits both transmission and reception of a modulated carrier signal from a location and reception at such location of a modulated carrier signal. Each location of such a two-way radio communication system contains both a transmitter and a receiver. The transmitter and the receiver positioned at a single location typically comprise a unit referred to as a radio transceiver, or more simply, a transceiver.

A cellular communication system is one type of two-way radio communication system in which communication is permitted with a radio transceiver positioned at any location within a geographic area encompassed by the cellular communication system.

A cellular communication system is created by positioning a plurality of fixed-site radio transceivers, referred to as base stations or base sites, at spaced-apart locations throughout a geographic area. The base stations are connected to a conventional, wireline telephonic network. Associated with each base station of the plurality of base stations is a portion of the geographic area encompassed by the cellular communication system. Such portions are referred to as cells. Each of the plurality of cells is defined by one of the base stations of the plurality of base stations, and the plurality of cells

together define the coverage area of the cellular communication system.

A radio transceiver, referred to in a cellular communication system as a cellular radiotelephone or, more simply, a cellular phone, positioned at any location within the coverage area of the cellular communication system, is able to communicate with a user of the conventional, wireline, telephonic network by way of a base station. Modulated carrier signals generated by the radiotelephone are transmitted to a base station, and modulated carrier signals generated by the base station are transmitted to the radiotelephone, thereby to effectuate two-way communication therebetween. (A signal received by a base station is then transmitted to a desired location of a conventional, wireline network by conventional telephony techniques. And, signals generated at a location of the wireline network are transmitted to a base station by conventional telephony techniques, thereafter to be transmitted to the radiotelephone by the base station.)

Increased usage of cellular communication systems has resulted, in some instances, in the full utilization of every available transmission channel of the frequency band allocated for cellular radiotelephone communication. As a result, various ideas have been proposed to utilize more efficiently the frequency band allocated for radiotelephone communications. By more efficiently utilizing the frequency band allocated for radiotelephone communications, the transmission capacity of an existing, cellular communication system may be increased.

The transmission capacity of the cellular communication system may be increased by minimizing the modulation spectrum of the modulated signal transmitted by a transmitter to permit thereby a greater number of modulated signals to be transmitted simultaneously. Additionally, by minimizing the amount of time required to transmit a modulated signal, a greater number of modulated signals may be sequentially transmitted.

By converting a communication signal into digital form prior to transmission thereof, the resultant modulated signal is typically of

a smaller modulation spectrum than a corresponding modulated signal comprised of a communication signal that has not been converted into discrete form. Additionally, when the communication signal is converted into digital form prior to modulation thereof, the resultant, modulated signal may be transmitted in short bursts, and more than one modulated signal may be transmitted sequentially upon a single, conventionally-defined, frequency channel. (As more than one modulated signal may be transmitted upon a single, conventionally-defined, frequency channel, the term frequency channel is sometimes referred to as the portion of the conventionally-defined frequency channel during which a particular transmitter transmits a modulated signal to a particular receiver. Hence, in a communication scheme in which modulated signals are transmitted in discrete bursts, two or more frequency channels may be defined upon a single, conventionally-defined, frequency channel.)

As a single frequency channel is utilized to transmit two or more separate signals during nonoverlapping time periods, a method of signal transmission is referred to as a time division method. A communication system incorporating such a time division method of signal transmission includes a Time Division Multiple Access communication system or, more simply, a TDMA communication system.

A TDMA communication system includes a transmitter operative to transmit signals to a receiver in intermittent bursts during intermittent time periods. Such signal transmitted to a particular receiver operative in a TDMA communication system shall hereinafter, at times, be referred to as a TDMA signal.

A TDMA communication system is advantageously utilized as a cellular communication system as, during time periods in which a base station does not transmit a TDMA signal to a particular radiotelephone, other TDMA signals may be transmitted. In particular, the radiotelephone to which the base station transmits a TDMA signal may, in turn, transmit a TDMA signal to the base station, thereby permitting two-way communication between the base station and the radiotelephone upon a single, conventionally-defined

frequency channel as signals transmitted to the radiotelephone by the base station, and by the radiotelephone to the base station may be timed to occur during alternate time periods.

As the transmitter and receiver circuitry portions of the radiotelephone operative in such a TDMA communication system are required to be operable only during alternate time periods, certain circuitry portions of radiotelephones operable in conventional, cellular communication systems are not required. For instance, duplexer filters positioned to connect both the transmitter circuitry portion and the receiver circuitry portion of the conventional, cellular radiotelephone and the radiotelephone antenna theretogether, are not required to form portions of radiotelephones operable in a TDMA communication system as the receiver and transmitter circuitry portions of such radiotelephone need not be operable simultaneously. Rather, switch circuitry may be utilized alternately to connect the receiver circuitry portion with the radiotelephone antenna or the transmitter circuitry portion with the radiotelephone antenna.

Radiotelephones constructed to be operable in either a conventional, cellular communication system or in a TDMA communication system each contain filters for removing undesired signals, both those generated during generation of modulated signals by transmitter circuitry of the radiotelephones and also for removing undesired signal portions of signals received by the radiotelephones. More particularly, the radiotelephones include both transmit and receive filters.

A transmit filter is utilized to remove harmonic signals and other undesired signals formed during generation of the transmit signal by transmitter circuitry of the radiotelephone. (For instance, during mixing processes in which the information signal is impressed upon a carrier signal, undesired harmonic signals are also generated. Such undesired signals are filtered by the transmit filter prior to transmission of a modulated signal by the transmitter.)

A receive filter is utilized as a broadband filter for filtering signals received by the transceiver which are of frequencies beyond a frequency bandwidth of interest. (For instance, if a signal

transmitted to the radiotelephone is transmitted upon a frequency channel of a frequency bandwidth of a range of frequencies encompassed by a frequency band allocated for radiotelephone communications, the receive filter is of a frequency passband which passes signals of frequencies within the frequency band allocated for the radiotelephone communications, but which rejects signals which are of frequencies beyond the frequency band allocated for radiotelephone communications.)

Radio transceivers operable in conventional, cellular communication systems are operable simultaneously to receive and to transmit modulated signals. Hence, both the transmitter and the receiver circuitry of such radiotelephones must be simultaneously operable. In such radiotelephones, duplexer filters, briefly noted hereinabove, are oftentimes utilized as the transmit and receive filters. Typically, a duplexer filter is formed of a block of ceramic material, cavities forming inner conductors of transmission lines are formed to extend through the ceramic block, and a coating of electrically-conductive material is formed upon at least portions of the ceramic block. A first portion of the duplexer filter forms the transmit filter and a second portion of the duplexer filter forms the receive filter. Because only a single ceramic block contains both the transmit and the receive filters, the physical dimensional requirements of a duplexer filter are somewhat less than the physical dimensional requirements of separate transmit and receiver filters.

However, when the transceiver is operable in a TDMA communication scheme wherein the transmitter and the receiver circuitry need not be simultaneously operable, the transmit and receive filters similarly need not be simultaneously operable. Heretofore, though, a single filter serving both as a transmit filter and as a receive filter has not been utilized as the filter characteristics required of the transmit and the receive filters are oftentimes dissimilar. That is to say, a single, conventional, ceramic block filter constructed to form a bandpass filter has fixed filter characteristics (i.e., the frequency of a particular filter is unalterable and the filter cannot be tuned). Hence, a single, ceramic block filter

having a fixed, frequency passband and center frequency cannot be utilized to form both the transmit and receive filters of a radiotelephone operable in a TDMA communication scheme.

A filter circuit having frequency characteristics which may be varied would permit a single filter circuit to be utilized as both a receive filter and a transmit filter.

What is needed, therefore, is a filter circuit which is tunable to permit, thereby, operation of the filter circuit as both a receive filter and a transmit filter in a radiotelephone.

Summary of the Invention

The present invention, accordingly, advantageously provides a tunable filter circuit and associated method therefor.

The present invention further advantageously provides a tunable filter circuit for a radio transceiver having radio circuitry operable alternately to generate a transmit signal or to receive a receive signal.

The present invention includes further advantages and features, the details of which will become more readily apparent by reading the detailed description of the preferred embodiments hereinbelow.

In accordance with the present invention, therefore, a tunable filter circuit is disclosed. The tunable filter circuit includes a dielectric block defining top, bottom, and at least first and second side surfaces. At least one longitudinally-extending resonator defined by sidewalls of at least one cavity is formed to extend longitudinally along a longitudinal axis between the top and bottom surfaces of the dielectric block. A coating of an electrically-conductive material substantially covers at least a portion of the bottom and the at least first and second side surfaces and the sidewalls of the cavity defining the at least one longitudinally-extending resonator. At least one variable capacitor is coupled in an electrical connection with the at least one resonator wherein the variable capacitor is variable to be of at least either a first capacitive value and a second capacitive value.

Brief Description of the Drawings

The present invention will be better understood when read in light of the accompanying drawings in which:

FIG 1. is a block diagram of a radio transceiver including the tunable filter circuit of a preferred embodiment of the present invention;

FIG. 2 is a partial plan view, partial electrical schematic of a portion of the tunable filter circuit of a preferred embodiment of the present invention;

FIG. 3 is an electrical schematic representation of the portion of the tunable filter circuit shown in FIG. 2;

FIG. 4 is an electrical schematic of a tunable filter circuit of a preferred embodiment of the present invention;

FIG. 5 is a perspective view of the tunable filter shown in the electrical schematic of FIG. 4, here mounted upon an electrical circuit board; and

FIG. 6 is a logical flow diagram listing the method steps of the method of a preferred embodiment of the present invention.

Description of the Preferred Embodiments

Turning first to the block diagram of FIG. 1, a radio transceiver, referred to generally by reference numeral 100, of a preferred embodiment of the present invention is shown. Radio transceiver 100 is representative of a cellular radiotelephone operable in a TDMA communication scheme. Radio transceiver 100 includes transmitter circuitry 106 which is operative to generate and modulate a signal forming the transmit signal which may be transmitted by transceiver 100. Radio transceiver 100 further includes receiver circuitry 112 to down-convert and to demodulate a modulated signal transmitted to the transceiver 100, i.e., the receive signal.

As mentioned hereinabove, because a radio transceiver operable in a TDMA communication scheme is operable to transmit and to receive modulated signals during dissimilar time periods, transmitter and receiver circuitry 106 and 112 need not be simultaneously operable to transmit and to receive, respectively, the modulated signals. Rather, transmitter and receiver circuitry 106 and 112 need only be operable to transmit and to receive the modulated signals during time periods in which signals are to be transmitted by, or to be received by, transceiver 100.

Accordingly, lines extending from both transmitter and receiver circuitry 106 and 112 are coupled to switch circuit 118. Line 124 extending from switch circuit 118 is coupled alternately to transmitter circuitry 106 or receiver circuitry 112 depending upon the positioning of switch circuit 118.

During time periods in which transceiver 100 is to be operative to transmit a transmit signal, switch circuit 118 is positioned to connect transmitter circuitry 106 with line 124. And, during time periods in which transceiver 100 is to receive a modulated signal transmitted thereto, switch circuit 118 is positioned to connect line 124 with receiver circuitry 112.

Positioning of switch circuit 118 is determined by a signal supplied to switch circuit 118 on line 130. The signal applied to switch circuit 118 on line 130 may, for example, be supplied by processor circuitry (not shown in the figure) of the transceiver.

Line 124 of switch circuit 118 is coupled to an input of tunable filter circuit 140. Tunable filter circuit 140, as shall be noted in greater detail hereinbelow, includes, as a portion thereof, a ceramic block filter and also variable capacitors. The variable capacitors and the ceramic block filter together form a filter circuit having a filter characteristic. Because the capacitive values of the variable capacitors may be varied, the filter characteristics of the filter circuit may also be varied. That is to say, the filter circuit may be tuned. Lines 146 extending to filter circuit 140 permit control signals to be applied to the variable capacitors of filter circuit 140 to control selection of the capacitive values of the variable capacitors and,

hence, to control selection of the filter characteristics of the filter circuit.

In one preferred embodiment of the present invention, the control signals applied to filter 140 on line 146 are of either of two values, thereby to cause the capacitive values of the variable capacitors to be of either of two values. Thereby, the filter characteristics of filter 140 are selectable to be of two different sets of characteristics. In other preferred embodiments of the present invention, the control signals applied to filter 140 on line 146 are of any of many various levels, thereby permitting the filter characteristics of tunable filter 140 to be of any of many various characteristics.

When switch circuit 118 is positioned to connect transmitter circuitry 106 with line 124, filter circuit 140 is operative to filter the signal generated by transmitter circuitry 106 and to generate a filtered signal on line 148. Line 148, in turn, is coupled to transceiver antenna 149 whereat the filtered signal generated by filter circuit 140 is transmitted therefrom. When, conversely, switch circuit 118 is positioned to interconnect output line 124 and receiver circuitry 112, a signal received by transceiver antenna 149 and generated on line 148 is filtered by filter circuit 140, and a filtered signal is generated on line 124 and supplied to receiver circuitry 112.

Because the filter characteristics, namely the filter passband and center frequency of filter circuit 140 may be varied by appropriate application of control signals thereto on line 146, only a single filter, here filter circuit 140, is required in substitution for separate receive and transmit filters (or, a duplexer filter having two filter portions).

Turning next to the partial plan view, partial electrical circuit schematic of FIG. 2, a portion of a tunable filter circuit, here referred to generally by reference numeral 240, is shown. Tunable filter circuit 240 of FIG. 2 corresponds to filter circuit 140 of transceiver 100 of FIG. 1. In the plan view of FIG. 2, a portion of top surface 250 of a block of ceramic (or other dielectric) material is illustrated. Top surface 250 of the ceramic block comprising a portion of filter circuit 240 is generally planar in configuration.

Aperture 252 formed of a top end portion of a cavity forming a transmission line which extends longitudinally through the ceramic block is formed at top surface 250. A coating 256 of electrically-conductive material is formed about aperture 252. (Electrically-conductive material is also formed upon sidewalls of the cavity extending through the ceramic block and which defines the transmission line.) Other coatings, here represented by rectangular areas 258 and 260 of electrically-conductive material, are also coated upon top surface 250 of the ceramic block forming a portion of filter circuit 240. The coatings of the electrically-conductive material represented by rectangular areas 258 and 260 are electrically coupled to additional coatings of the electrically-conductive material coated upon adjacent side surfaces (not shown in the plan view of FIG. 2) of the ceramic block. And such coatings represented by rectangular areas 258 and 260 and also the coatings formed upon the adjacent side surfaces are coupled to an electrical ground plane.

The coatings of the electrically-conductive material represented by rectangular areas 258 and 260 are isolated from coating 256 formed about aperture 252. (It should further be noted that coating 256 and rectangular areas 258 and 260 representative of coatings are shown for purposes of explanation and that, in most instances, the configurations of the coated portions of top surface 250 are of more complex configurations.) Because coating 256 is isolated and spaced-apart from rectangular area 258, the spaced-apart coatings form capacitive plates which are capacitively coupled theretogether.

Rectangular area 261 is further shown in the figure and is representative of a coating of electrically-conductive material positioned between coating 256 and rectangular area 260. The coating represented by rectangular area 261 is electrically-isolated from both coating 256 and the coating represented by rectangular area 260. Capacitor 263 is representative of the capacitive loading between the coating represented by rectangular area 261 and the coating represented by rectangular area 260.

The capacitive values of capacitors 262 and 263 are fixed (i.e., unalterable) and are dependent upon the surface areas of the coatings

and the distances apart which such coatings are spaced. In one embodiment of the present invention, a discrete capacitor is additionally positioned between areas 260 and 261, and, in such an embodiment, capacitor 262 is also representative of such discrete capacitor.

Variable capacitor 264, such as a varactor (e.g., a voltage variable capacitor, VVC) is mounted upon top surface 250 and is represented in the figure in a series connection with capacitor 263. A first side of variable capacitor 264 is coupled to coating 256 formed about aperture 252, and a second side of variable capacitor 264 is spaced-apart from coating 256 in a capacitive connection therewith. Hence, the second side of variable capacitor 264 is illustrated in electrical connection with capacitor 263 representative of the capacitive loading between coating 256 and rectangular area 260.

In one preferred embodiment of the present invention, capacitor 264 is mounted upon top surface 250 and coupled to coating 256 and rectangular area 260 by a solder connection; in another preferred embodiment of the present invention, capacitor 264 is formed of metal oxide semiconductor materials which are grown upon top surface 250 by conventional techniques. Line 266 which extends to capacitor 264 is further shown in the figure. Line 266 permits application of a control signal to capacitor 264, and here a voltage signal, to control the capacitive level of variable capacitor 264.

FIG. 3 is an electrical schematic representation of the portion of tunable filter circuit 240 shown in the partial plan view, partial electrical schematic of FIG. 2. Reference numerals utilized to identify component elements of filter circuit 240 of FIG.2 are again utilized in the electrical schematic representation of FIG. 3. A transmission line, here represented by reference numeral 252' to correspond to aperture 252 of FIG. 2 formed of the top end of the cavity, comprising the transmission line, extending through the ceramic block is shown in the figure. Capacitors 262, 263, and 264 are together representative of capacitive loadings of transmission line 252' to ground. Capacitors 262, 263, and 264 together function to foreshorten the resonator which forms transmission line 252'.

The capacitance of an equivalent circuit of capacitors 262, 263, and 264 for any particular capacitive level of capacitor 264 may, of course, be readily ascertained. By varying the capacitive level of variable capacitor 264, the equivalent capacitance of capacitors 262, 263, and 264 may be altered. Accordingly, by appropriate selection of the capacitive value of capacitor 264, the equivalent capacitance of the equivalent circuit may be selected as desired.

Turning next to the electrical schematic of FIG. 4, a tunable filter circuit, here referred to generally by reference numeral 340, is shown. Filter 340 is a multi-pole, tunable filter having filter characteristics (namely, a filter passband and center frequency) which are dependent upon the component values of the component elements comprising the filter. Analogous to filter 240 of FIGS. 2 and 3, filter 340 also includes a resonating cavity comprising a transmission line formed to extend through a block of ceramic material. As filter 340 is a multi-pole filter, a plurality of resonating cavities forming a plurality of transmission lines are formed to extend through the block of ceramic material. Hence, the electrical circuit schematic of the portion of tunable filter 240 of FIGS. 2 and 3 corresponds to a single one of the various resonating cavities comprising multi-pole, tunable filter 340.

Accordingly, the electrical circuit schematic of FIG. 4 represents four resonating cavities comprising four transmission lines formed to extend through a block of ceramic material. First transmission line 352' of filter 340 is positioned in parallel with a capacitive circuit formed of capacitors 362, 363, and 364. Capacitors 362, 363, and 364, analogous to capacitors 262, 263, and 264 of FIGs. 2 and 3, together capacitively load transmission line 352' to ground.

First transmission line 352' is inductively coupled, as represented by transmission line 368, with a second transmission line 372'.

Second transmission line 372' of filter 340 is positioned in parallel with a capacitive circuit formed of capacitors 382, 383, and 384. Capacitors 382, 383, and 384 are also analogous to capacitors 262,

263, and 264 of FIGs. 2 and 3, and also together capacitively load transmission line 372' to ground.

Transmission line 372' is, in turn, inductively coupled, as represented by transmission line 388, to third transmission line 392'.

Third transmission line 392' of filter 340 is positioned in parallel with a capacitive circuit formed of capacitors 402, 403, and 404 which, further analogous to capacitors 262, 263, and 264 of FIGs. 2 and 3, together capacitively load transmission line 392' to ground.

Transmission line 392' is inductively coupled, as represented by transmission line 408, to fourth transmission line 412'.

Fourth transmission line 412' of filter 340 is positioned in parallel with a capacitive circuit formed of capacitors 422, 423, and 424 which, also analogous to capacitors 262, 263, and 264 of FIGs. 2 and 3, together capacitively load transmission line 412' to ground.

Filter circuit 340 of FIG. 4 further illustrates capacitor pairs 426-430 and 434-438 which form an input/output coupling network at opposing sides of the circuit.

Because the capacitive values of variable capacitors 364, 384, 404, and 424 may be varied, the filter characteristics of filter circuit 340 may be varied responsive to variance of the capacitive values of the variable capacitors. Hence, by suitable selection of the capacitive values of the various, variable capacitors, the filter characteristics of filter 340 may be selected, as desired.

Block 440, representative of a control voltage generator is further illustrated in FIG. 4. Control voltage generator 440 is operative to apply control signals to the variable capacitors 364, 384, 404, and 424. In one preferred embodiment of the present invention, the control signals generated by control voltage 440 are of two separate values to cause the variable capacitors alternately to be of a first capacitive value or a second capacitive value. In another preferred embodiment of the present invention, control voltage 440 generates control signals to the variable capacitors to permit incremental changes in the capacitive values of the respective, variable capacitors.

Turning next to FIG. 5, filter circuit 340 shown in the electrical schematic representation of FIG. 4 is shown in perspective, here mounted upon electrical circuit board 444.

The ceramic block forming a portion of filter circuit 340 illustrates, in the view of FIG. 5, top face surface 450 and side surfaces 454 and 458. (Additional side surfaces of the ceramic block are hidden from view in the figure.) Openings defined by transmission lines 352', 372', 392', and 412' are formed at top surface 450. Variable capacitors, here varactors or voltage variable capacitors, 364, 384, 404, and 424 are also formed upon top surface 450. The variable capacitors 364, 384, 404, and 424 are positioned in manners analogous to the positioning of variable capacitor 264 of filter circuit 240 of FIGS. 2 and 3. Additionally formed on top surface 450 are couplers 466 and 472. Couplers 466 and 472 correspond to coupling ports formed at opposing ends of filter circuit 340 shown in the electrical schematic representation of FIG. 4.

The ceramic block comprising a portion of filter circuit 340 is mounted upon circuit board 444 in conventional manner to connect couplers 466 and 472 to circuit paths disposed upon circuit board 444. In a similar manner, circuit paths may be formed to extend to variable capacitors 364, 384, 404, and 424 to apply control signals to control the capacitive values of such variable capacitors.

As mentioned previously, particularly with respect to the block diagram of FIG. 1, the tunable filter circuits of the preferred embodiments of the present invention may be advantageously utilized to form a portion of a cellular radiotelephone operative in a TDMA communication scheme. In such an application, the center frequency of the filter circuit must be of a first center frequency (and of a first bandwidth) when the radiotelephone is operative to receive modulated signals and must be of a second center frequency (and of a second bandwidth) when the radiotelephone is operative to transmit modulated signals. For instance, when transmitting modulated signals, the filter must be of a center frequency of , for example, 897.5 MHz, and when the radiotelephone is operative to receive modulated signals, the center frequency of the filter must be of a frequency of

942.5 MHz. As frequency is inversely related to the square root of capacitance, a capacitive ratio, CR, is determined by the following equation:

$$CR = C_{max}/C_{min} = (F_{min})^2/(F_{max})^2$$

wherein:

C_{max}= the equivalent capacitance for the first, maximum center frequency;

C_{min} is the equivalent capacitance required of the second, minimum center frequency;

F_{max} is the first , maximum center frequency; and

F_{min} is the second, minimum center frequency.

In the example just-shown, the capacitive ratio is 1.103 (i.e., $(942.5/897.5)^2 = 1.103$). Hence, if the equivalent capacitance required of the filter circuit when the center frequency is to be 942 MHz is 2 pF, the equivalent capacitance required of the filter circuit when the center frequency is to be of 897 MHz is of a value of 2.206 pF. Control signals applied to the various variable capacitors of the tunable filter must permit such equivalent capacitances to be formed.

Finally turning now to the logical flow diagram of FIG. 6, the method steps of the method, referred to generally by reference numeral 800, of a preferred embodiment of the present invention are listed. Method 600 constructs a filter of a block of dielectric material defining top, bottom, and at least first and second side surfaces.

First, and as indicated by block 806, at least one longitudinally-extending resonator is formed between the top and bottom surfaces of the dielectric block.

Next, and as indicated by block 812, at least a portion of the bottom and first and second side surfaces of the dielectric block are covered with a coating of an electrically-conductive material.

And, as indicated by block 818, at least one variable capacitor is coupled in an electrical connection with the at least one resonator wherein the variable capacitor is variable to be of at least either a first capacitive value or a second capacitive value.

While the present invention has been described in connection with the preferred embodiments shown in the various figures, it is to be understood that other similar embodiments may be used and modifications and additions may be made to the described embodiments for performing the same function of the present invention without deviating therefrom. Therefore, the present invention should not be limited to any single embodiment, but rather construed in breadth and scope in accordance with the recitation of the appended claims.

Claims

What is claimed is:

1. A tunable filter circuit comprising:

a dielectric block defining top, bottom, and at least first and second side surfaces;

at least one longitudinally-extending resonator defined by sidewalls of at least one cavity formed to extend longitudinally along a longitudinal axis thereof between the top and bottom surfaces of the dielectric block;

a coating of an electrically-conductive material substantially covering at least a portion of the bottom and the at least first and second side surfaces and the sidewalls of the cavity defining the at least one longitudinally-extending resonator; and

at least one variable capacitor coupled in an electrical connection with the at least one resonator, said variable capacitor of a capacitance of at least either a first capacitive value or a second capacitive value.

2. The tunable filter circuit of claim 1 wherein the at least one variable capacitor is mounted upon the top surface of the dielectric block.

3. The tunable filter circuit of claim 1 wherein said coating of the electrically-conductive material is further coated upon portions of the top surface of the dielectric block about an opening defined by a top end portion of the at least one longitudinally-extending resonator, said coating of the electrically-conductive material formed about the opening defined by the top end portion of the at least one resonator being electrically coupled to the coating of

the electrically-conductive material coated upon the sidewalls of the cavity defining the at least one resonator.

4. The tunable filter circuit of claim 3 wherein said coating of the electrically-conductive material is further coated upon portions of the top surface of the dielectric block and spaced-apart from the coating of the electrically-conductive material positioned about the opening defined by the top end portion of the at least one longitudinally-extending resonator.

5. The tunable filter circuit of claim 4 wherein a first side portion of the at least one variable capacitor is mounted upon the coating of the electrically-conductive material formed about the opening defined by the top end portion of the at least one resonator.

6. The tunable filter circuit of claim 1 further comprising a control signal generator for generating a control signal to control selection of the capacitive values of the variable capacitor and wherein said control signal generator comprises a voltage source operable to generate a voltage signal of at least either a first level or a second level.

7. The tunable filter circuit of claim 1 wherein said at least one longitudinally-extending resonator comprises at least two longitudinally-extending resonators formed to extend along respective longitudinal axes thereof between the top and bottom surfaces of the dielectric block.

8. The tunable filter circuit of claim 7 wherein said at least one variable capacitor comprises at least two variable capacitors wherein a first variable capacitor of the at least two variable capacitors is coupled in an electrical connection with a first resonator of the at least two resonators and a second variable capacitor of the at least two variable capacitors is coupled in an electrical connection with a second resonator of the at least two resonators.

9. The tunable filter circuit of claim 8 further comprising a control signal generator for generating a control signal to control selection of the capacitive values of the first and second variable capacitors.

10. A method for constructing a filter of a block of dielectric material defining top, bottom, and at least first and second side surfaces, said method comprising the steps of:

forming at least one longitudinally-extending resonator defined by sidewalls of at least one cavity to extend longitudinally along a longitudinal axis thereof between the top and bottom surfaces of the dielectric block;

covering at least a portion of the bottom and the at least first and second side surfaces of the dielectric block and the sidewalls of the cavity defining the at least one longitudinally-extending resonator with a coating of an electrically-conductive material; and

coupling at least one variable capacitor in an electrical connection with the at least one resonator wherein the variable capacitor is variable to be of at least either a first capacitive value or a second capacitive value.

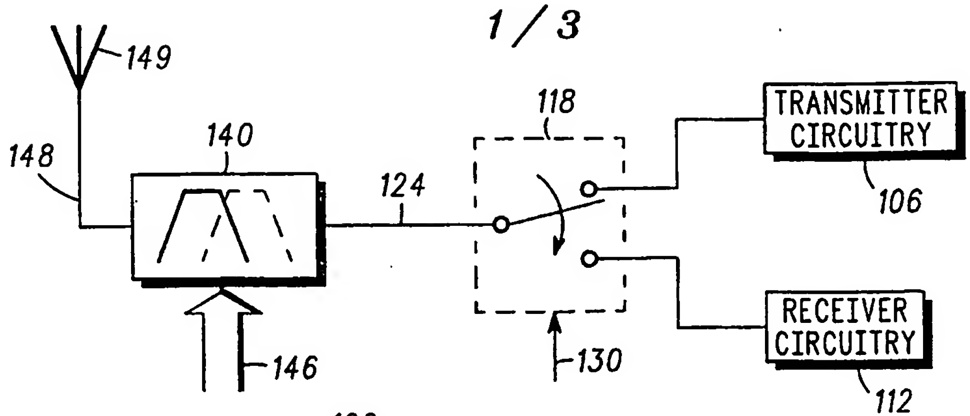


FIG. 1

FIG. 2

240

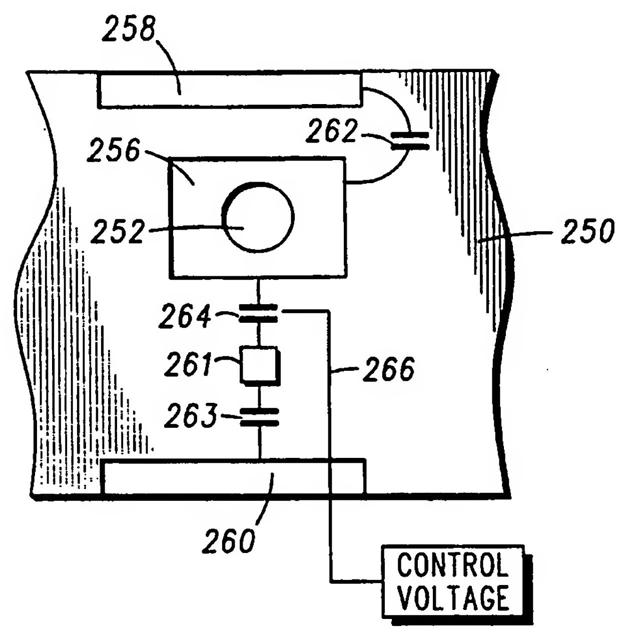


FIG. 3

240

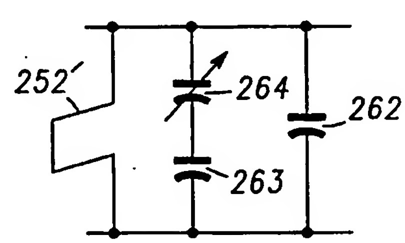
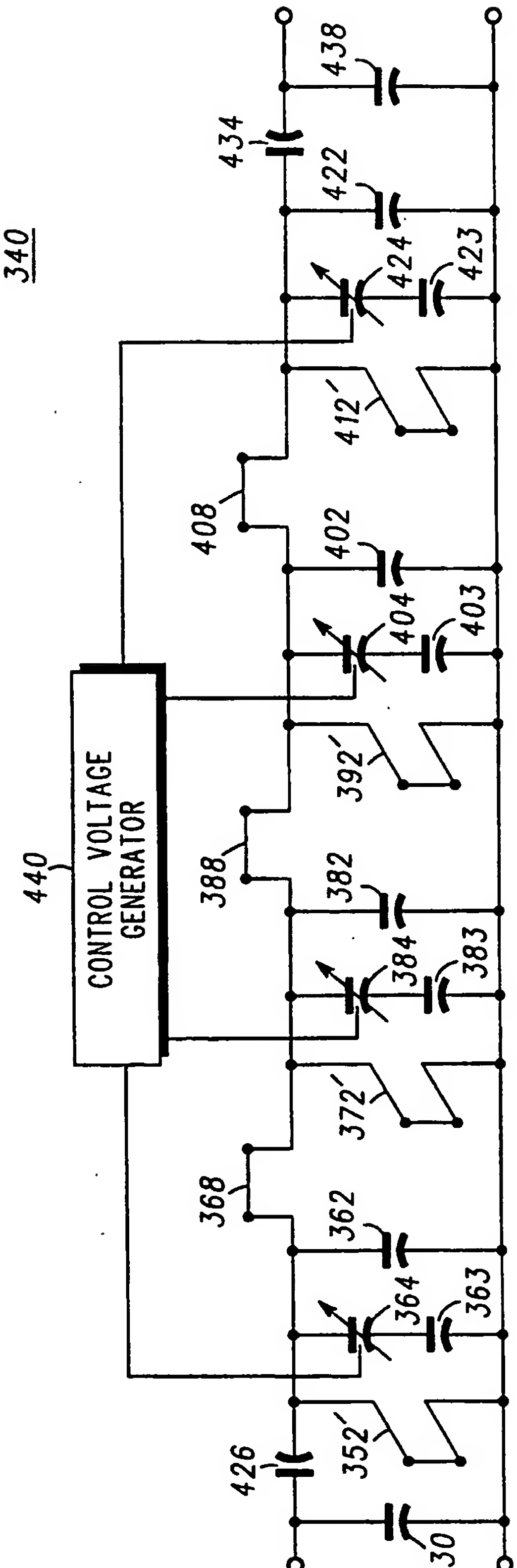


FIG. 4

340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434
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363
352
426
430
440
CONTROL VOLTAGE
GENERATOR

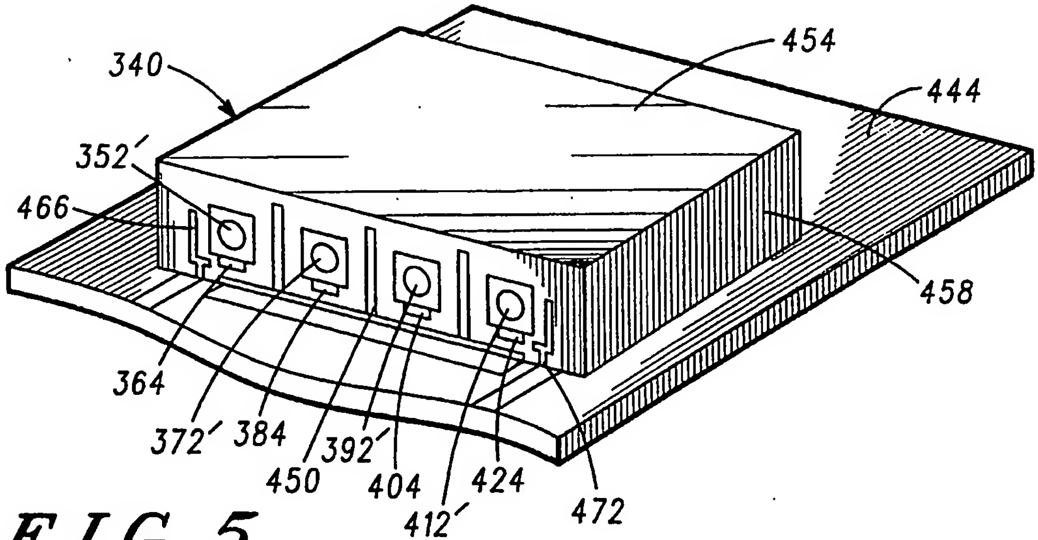
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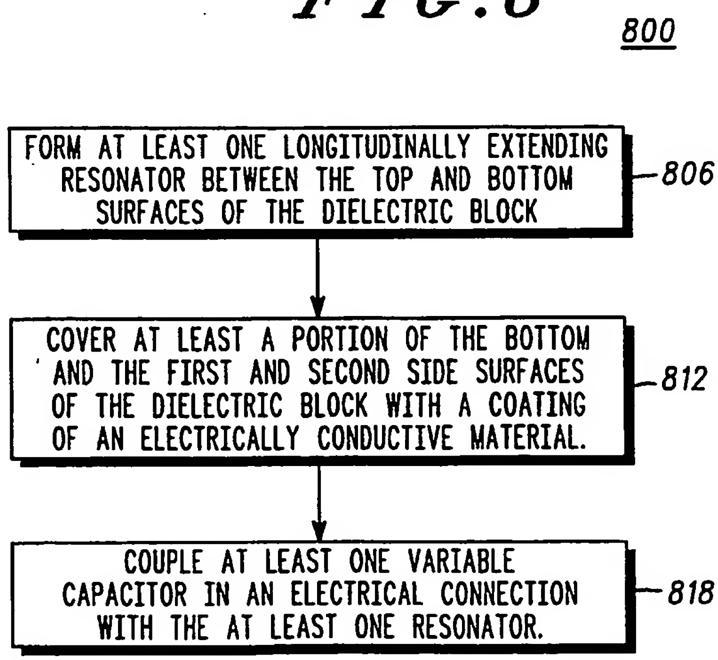
FIG.5

FIG.6


800
FORM AT LEAST ONE LONGITUDINALLY EXTENDING RESONATOR BETWEEN THE TOP AND BOTTOM SURFACES OF THE DIELECTRIC BLOCK
806
COVER AT LEAST A PORTION OF THE BOTTOM AND THE FIRST AND SECOND SIDE SURFACES OF THE DIELECTRIC BLOCK WITH A COATING OF AN ELECTRICALLY CONDUCTIVE MATERIAL.
812
COUPLE AT LEAST ONE VARIABLE CAPACITOR IN AN ELECTRICAL CONNECTION WITH THE AT LEAST ONE RESONATOR.
818

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/04363

A. CLASSIFICATION OF SUBJECT MATTER
IPC(5) :H04B 1/16
US CL :455/340
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 455/340,78,79,80,81,82,83,84,306; 333/202,206,207,202B,219.1,223

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ----- Y	US, A, 4,721,932 (WEST) 26 January 1988, col. 1, lines 21-55, col. 4, lines 21-34.	1,6,7,8,9 ---------- 2-5,10
A	US, A, 4,462,009 (LANDT et al) 24 July 1984, col. 2, line 47 - col. 3, line 25.	1-10
A	US, A, 4,742,562 (KOMMRUSCH) 03 May 1988, fig. 1, col. 1, line 65 - col. 2, line 14.	1-10
A	US, A, 5,109,536 (KOMMRUSCH) 28 April 1992, fig. 7, col. 7, lines 55-65.	1-10
A	EP, A, 333-419 (BEESLEY et al) 20 September 1989, fig. 1, col. 1, lines 22-32.	1-10

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be part of particular relevance
"E" earlier document published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 JUNE 1994	JUL 20 1994
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer PHILIP J. SOBUTKA Telephone No. (703) 305-4825

Form PCT/ISA/210 (second sheet)(July 1992)*

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/04363

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A,P	US, A, 5,227,748 (SROKA) 13 July 1993, fig. 2, col. 2, line 58 - col. 3, line 5, col. 3, line 50 - col. 4, line 17, col. 4, lines 43-46.	1-10
A,P	JP, A, 5-136706 (TSUTSUI) 01 June 1993, fig. 1.	1-10